AD_____

GRANT NUMBER DAMD17-94-J-4115

TITLE: Improving 5-Fluorouracil Chemotherapy in Breast Cancer Patients by Monitoring Dihydropyrimidine Dehydrogenase Activity

PRINCIPAL INVESTIGATOR: Zhihong Lu, M.D., Ph.D.

CONTRACTING ORGANIZATION: University of Alabama at Birmingham
Birmingham, Alabama 35294-0111

REPORT DATE: September 1996

TYPE OF REPORT: Annual

PREPARED FOR: Commander
U.S. Army Medical Research and Materiel Command
Fort Detrick, Frederick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1996	Annual (15 Aug 95 - 14 Aug 96)

4. TITLE AND SUBTITLE Improving 5-Fluorouracil Chemotherapy in Breast Cancer Patients by Monitoring Dihydrophyrimidine Dehydrogenase Activity

5. FUNDING NUMBERS

DAMD17-94-J-4115

6. AUTHOR(S)

Zhihong Lu, M.D., Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Alabama at Birmingham
Birmingham, Alabama 35294-0111

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Commander
U.S. Army Medical Research and Materiel Command
Fort Detrick, MD 21702-5012

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200*

The purpose of this project is to improve 5-fluorouracil (5-FU)-based chemotherapy in the treatment of breast cancer by monitoring the key 5-FU metabolic enzyme, dihydropyrimidine dehydrogenase (DPD). In the second year, we continued: 1)to characterize DPD activity in breast cancer patients; 2)to establish the relationship between DPD activity and 5-FU-associated toxicity; and 3)to determine DPD activity in the liver and tumor tissues in cancer patients. DPD activity in peripheral blood mononuclear cells (PBM-DPD) was determined in 360 breast cancer patients, with mean PBM-DPD (0.26±0.01 nmol/min/mg protein) being significantly lower than that observed in female controls (0.44±0.02, $p<0.005$). ANOVA analysis indicates that only disease difference (breast cancer vs. normal subjects) is significant after adjustment for race and age. Nine (3%) patients have DPD deficiency. Significant lower DPD activity in breast cancer patients may predispose to 5-FU-associated toxicity. DPD activity was also determined in tumor and normal liver specimens from 50 cancer patients. Mean liver DPD activity (0.45±0.02) was higher than that in normal population (0.37 ± 0.02) and in tumor tissues (0.34±0.03, $p<0.01$). These results should be useful in the future clinical evaluation of 5-FU-based chemotherapy.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Humans, Clinical Trials, Anatomical Samples, Breast Cancer Chemotherapy, 5-Fluorouracil Toxicity, Dihydropyrimidine Dehydrogenase, Dose Prediction	25
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

FOREWORD

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the US Army.

____ Where copyrighted material is quoted, permission has been obtained to use such material.

____ Where material from documents designated for limited distribution is quoted, permission has been obtained to use the material.

__X__ Citations of commercial organizations and trade names in this report do not constitute an official Department of Army endorsement or approval of the products or services of these organizations.

____ In conducting research using animals, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Resources, National Research Council (NIH Publication No. 86-23, Revised 1985).

____ For the protection of human subjects, the investigator(s) adhered to policies of applicable Federal Law 45 CFR 46.

____ In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to current guidelines promulgated by the National Institutes of Health.

____ In the conduct of research utilizing recombinant DNA, the investigator(s) adhered to the NIH Guidelines for Research Involving Recombinant DNA Molecules.

____ In the conduct of research involving hazardous organisms, the investigator(s) adhered to the CDC-NIH Guide for Biosafety in Microbiological and Biomedical Laboratories.

Zhihong Lu 9/09/96

PI - Signature Date

TABLE OF CONTENTS

INTRODUCTION

I. BACKGROUND

5-Fluorouracil (5-FU) is one of the most widely used anticancer drugs (1-2), ranking in the top three anticancer drugs prescribed in the U.S. (3). It is frequently used in the treatment of breast cancer (4). In general, 5-FU-associated toxicity occurs in the gastrointestinal mucosa and bone marrow (4,5) and, less frequently, in the neurologic system presenting as cerebellar ataxia and somnolence. Like many other antineoplastic drugs, 5-FU has a relatively narrow therapeutic index, such that toxicity is likely to increase as the dose is escalated. The biochemical mechanism of 5-FU-associated toxicities is thought to be related to its anabolic pathway, in particular, inhibition of thymidylate synthase and incorporation into RNA and DNA (1-2). However, 5-FU catabolic pathway may have a major role in 5-FU toxicity since more than 85% of administered 5-FU is metabolized by the catabolic pathway. Dihydropyrimidine dehydrogenase (DPD) is the initial and rate-limiting step in 5-FU catabolism (6), which is important in regulation of 5-FU metabolism, determining the availability of 5-FU for anabolism and further determining 5-FU therapeutic effects and/or toxicities.

Several clinical studies indicate the importance of DPD as a major determinant of 5-FU toxicity. Co-administration of thymidine with 5-FU (leading to release of thymine that competes DPD with 5-FU) has been shown to induce unexpected life-threatening toxicity (7,8,9). Pharmacokinetic studies of patients receiving 5-FU by continuous infusion demonstrated that plasma 5-FU levels varied throughout the day with a circadian pattern (10). A subsequent study examining patients receiving 5-FU by continuous infusion demonstrated that plasma 5-FU levels had a circadian variation that varied inversely with circadian variation in DPD from peripheral blood mononuclear (PBM) cells, suggesting that the plasma 5-FU levels were regulated by DPD (11). The relationship between DPD levels and 5-FU pharmacokinetics was also demonstrated by Fleming et al (12) in patients receiving 5-FU continuous infusion.

The importance of DPD in 5-FU pharmacokinetics and toxicity is further demonstrated in patients with DPD deficiency, a recently defined pharmacogenetic syndrome (13-18). Following 5-FU-based chemotherapy, these patients developed profound toxicity and eventually died. More importantly, in our earlier studies (14-17), ten of the 11 patients were women with either breast or colorectal cancer. In view of this striking sex difference in patient studies from our laboratory (14-17) and others (13), as well as the recently suggested sex-related difference in 5-FU clearance (18), it is important to determine if there is sex difference in DPD activity and in 5-FU toxicity by a large scale prospective study. Recently, in an NIH/NCI funded study, we determined the characteristics of DPD activity and established a baseline for this enzyme in the general population (17).

There are an increasing number of genetic polymorphisms recognized for drug metabolizing enzymes that may produce not only altered drug metabolism but also increased drug toxicity. Pharmacogenetic syndromes have now been described for many different types of drugs including cancer chemotherapy drugs (19). While decreased drug metabolism may result in altered pharmacokinetics and pharmacodynamics and hence increased toxicity with various classes of drugs, it can be particularly striking with cancer chemotherapy drugs since the therapeutic index is typically narrow. In the present project, we have been studying the pharmacogenetic syndrome of

DPD deficiency, potentially accounting for many of the cases of severe 5-FU toxicity, including death, seen in the clinic. The presence of genetic polymorphism in the population due to the presence of unknown molecular alteration(s) in DPD suggests that if DPD can be assessed prior to therapy severe toxicity may be avoided in the future. Although the mechanisms are unclear, the frequency of DPD deficiency in women and breast cancer patients appears to be higher than that in general population.

II. PURPOSE AND SIGNIFICANCE OF THE PROJECT

The long term objective of this project is to improve 5-FU chemotherapy in cancer patients through a better understanding of the genetic polymorphism of DPD and its role in determining 5-FU toxicity. Knowledge acquired from this project should be useful in the future to predict which patients may be susceptible to severe 5-FU toxicity, permitting modification of drug dose before chemotherapy. Specific objectives include:

1.) Determine in a prospective study the relationship between DPD activity and 5-FU toxicity.

Hypothesis 1- *-DPD has a major role in determining 5-FU toxicity with decreased enzyme activity being associated with greater toxicity. DPD activity in breast cancer patients may be used in predicting 5-FU toxicity and permitting modification of drug dose of 5-FU in chemotherapy of breast cancer.*

2.) Determine biochemical properties of DPD from peripheral blood mononuclear cells (PBM-DPD) of normal and deficient individuals.

Hypothesis 2-- *The mechanisms responsible for DPD deficiency may be related to DNA, RNA and protein levels. Comparison of DPD from deficient patients with DPD from normal individuals should provide insight into the mechanism of genetic polymorphism of DPD.*

As noted earlier, 5-FU continues to be one of the most widely used anticancer drugs (1-2), ranking in the top three anticancer drugs prescribed in the U.S. (3). It is one of the major chemotherapeutic agents in the treatment of breast cancer(4). However, the mechanisms responsible for 5-FU toxicity are not completely understood. Although toxicity from 5-FU is generally manageable, severe and life threatening toxicity does occur. As shown above DPD is the initial rate limiting enzyme in 5-FU catabolism and hence can ultimately regulate the amount of 5-FU available for anabolism. Furthermore, we have shown that there is evidence for variation in enzyme in the population, and that certain individuals who experience severe toxicity after 5-FU treatment are deficient in DPD activity. Preliminary studies indicate that DPD activity in breast cancer patients is lower than the general population. In addition, most DPD deficient patients identified by us and others were women. Furthermore, the frequency of DPD deficiency in breast cancer patients appears to be much higher than in the general population. Thus it appears highly desirable to determine in a prospective study the relationship between DPD activity and toxicity in patients receiving 5-FU, and to determine the mechanisms responsible for DPD deficiency.

METHODS AND MATERIALS

Chemicals and Radiochemical

5-FU, BSA, NADPH, and Histopaque were purchased from the Sigma Chemical Co. (St. Louis, MO). [^{3}H]-5-FU (25 Ci/mmol) was obtained from New England Nuclear Corp. (Boston, MA). The purity of unlabeled and labeled 5-FU was confirmed by HPLC (20) to be greater than 99%. All other solvents and reagents were purchased in the highest grade available.

The major buffer (buffer A) used in both the enzyme preparation and DPD assay contained 35 mM potassium phosphate, pH 7.4, 2.5 mM magnesium chloride, and 10 mM 2-mercaptoethanol. Since it is light-sensitive and unstable with long-term storage, NADPH, the critical cofactor in the enzyme reaction was freshly prepared.

Determination of PBM-DPD Activity in Breast Cancer Patients

Cancer Patients. In collaboration with the Oncology Clinic in the University of Alabama at Birmingham, breast cancer patients who were seen in the clinic and treated or to be treated with 5-FU (in combination with other agents) were assayed for DPD activity. Consent was obtained from each patient. Clinical data were also collected for further analysis.

Blood Collection and Isolation of PBM Cells. Blood samples (25 ml) were drawn from a peripheral vein into heparinized tubes and then loaded onto a centrifuge tube containing 15 ml Histopaque. After centrifugation at 500 x *g* for 30 min at 25°C, the PBM cell fraction was carefully removed and washed 3 times with PBS. Contaminating red blood cells were hypotonically lysed. The resulting PBM cells were used in the subsequent enzyme assay.

Preparation of PBM cytosol. Fresh PBM cells were suspended in buffer A then placed in an ice bath and lysed by sonication (3 times 10 sec with 30 sec interval between sonication). After centrifugation at 14, 000 x *g* for 15 min at 4°C, the supernatant was removed and used in the subsequent enzyme assay. Using the method of Bradford (21), the amount of protein in the sample was determined prior to enzyme assay in order to add appropriate amount protein into the reaction mixture.

Enzyme Assay DPD activity was determined by radioassay, measuring the catabolites of 5-FU formed by reversed-phase HPLC (17, 20). The reaction mixture contained 200 μM NADPH, 20 μM [^{3}H]-5-FU, buffer A, and enzyme solution (250-1000 μg total protein) in a final volume of 1 ml. The mixture was incubated at 37°C and 175 μl of the reaction sample was taken out at various times (5, 10, 20, 30, 60 min) and mixed with the same volume of ice-cold ethanol to stop the reaction. The mixture was then kept in a freezer (-20°C) for 30 min and subsequently filtered through a 0.2 μm Acro filter (Gelman Sciences, Ann Arbor, MI) prior to HPLC analysis.

Reversed-Phase HPLC Analysis Separation of 5-FU and its catabolites was performed by reversed-phase HPLC using a Hewlett-Packard 1050 HPLC system equipped with a spectrometric detector and chromatographic terminal (HP 3396 Series II Integrator). Two Hypersil 5 μm columns (Jones Chromatography, Littleton, CO) were used in tandem as the stationary phase. The columns were eluted at a flow rate of 1.0 ml/min with the mobile phase containing 1.5 mM potassium phosphate, pH 8.0, with 5 mM tetrabutylammonium hydrogen sulfate (17,20).

Fractions (1 ml) were collected into 7-ml scintillation vials, using a Redifrac fraction collector (Pharmacia LKB Biotechnology, Piscataway, NJ) and were mixed with 5.5 ml scintillation solvent. The radioactivity in each fraction was quantitated by liquid scintillation spectrometry (Beckman LS 6000). Under these conditions, typical retention times for dihydrofluorouracil and 5-FU were 9 and 21 min, respectively.

Determination of DPD Activity in Normal and Tumor Tissues from Cancer Patients

Patients and Samples. This part of study was carried out in collaboration with the Department of Medical Oncology, Cancer Hospital, Sun Yat-sen University of Medical Sciences in Guangzhou, China. Fifty cancer patients were enrolled in the present study. All patients were diagnosed with primary hepatocellular carcinoma that was relatively small and surgically removable. All patients gave informed consent to participate in this study. The protocol used in this study was approved by the University Institutional Review Board of Sun Yat-sen University of Medical Sciences. The hepatocellular carcinoma and the adjacent uninvolved liver tissue samples (about 10 g) were removed during surgery. Each sample was divided into two parts, one being used for pathologic evaluation and the other for DPD analysis. Specimens for pathologic evaluation were fixed in formalin solution. The samples for DPD analysis were frozen immediately and stored in liquid nitrogen until transported in dry ice to our laboratory in USA. These samples were then stored at -70 °C until DPD analysis. Permission to import biologic samples was obtained from US Center for Disease Control (CDC).

Sample Preparation. The slowly-thawed liver tissues were washed with ice-cold physiologic saline (0.9% NaCl), weighed, minced, and homogenized in 4 volumes of buffer A. The resulting homogenate was centrifuged at 100,000 x *g* for 60 min at 4 °C. The cytosolic fraction (supernatant) was removed and used in the subsequent analyses. DPD activity was determined immediately following the supernatant preparation. Prior to enzyme assay, the amount of protein in each sample was determined by the method of Bradford (21) in order to add the appropriate amount of protein to the enzyme reaction. The experimental conditions for enzyme reaction and HPLC analysis were essentially the same as described above.The reaction mixture in buffer A contained 20 μM [^{3}H]-5-fluorouracil, 200 μM NADPH, and sample solution (1 mg of total protein) in a final volume of 2 ml. The mixture was incubated at 37 °C and 350 μl aliquot was sampled at various times points (5, 10, 15, and 20 min) and mixed with the same volume of ice-cold ethanol to stop the reaction. The mixture was then kept in a freezer (-20 °C) for at least 30 min and subsequently centrifuged and filtered through a 0.2 μm Acro filter (Gelman Sciences, Ann Arbor, MI) prior to HPLC analysis.

Calculation of DPD Activity

For each sample, 5 determinations were run at various incubation times. After HPLC analysis, the amount of 5-FU catabolites at each time point was quantitated. The data was plotted using products formed (y) versus time (x) to calculate the slope of the reaction (products formed/min) by linear regression analysis. The slope was then divided by the amount of protein added to obtain the final result (DPD activity expressed as nmol/min/mg protein). For samples from cancer patients with DPD deficiency or liver samples with very low DPD activity, at least two separate assays were performed.

As demonstrated in our previous studies (9, 17), the radioassay was sensitive and accurate in determination of DPD activity in peripheral blood mononuclear cells and in liver samples. Using the assay conditions described above, the variations of inter- and intra-assay were found to be less

than 5%. For samples with extremely low enzyme activity, at least two separate assays were performed to verify the results.

Statistical Analysis

Mean DPD activity (and S.D. or S.E.) was calculated for each group by age, gender, and race. The differences of DPD activity among the groups by gender, age, and race were analyzed by ANOVA. To determine the distribution pattern in the general population, probability testing was used.

RESULTS

PBM-DPD Activity in Breast Cancer Patients

Using freshly prepared PBM cell samples, DPD activities of 360 breast cancer patients were determined. The population characteristics of this study are summarized in Table 1 (page 15). Distribution of PBM-DPD activity in this population is shown in Fig 1 (page 18). Statistical analysis by probability testing indicated that human PBM-DPD activity follows a normal distribution. In order to examine potential differences in age and race, further statistical analyses were carried out. The mean PBM-DPD activities in each group by age and race are also shown in Table 1 (page 15). Nine (3%) patients have been classified as DPD deficiency.

Statistical analyses indicated that mean PBM-DPD activity in breast cancer patients was significantly lower than that observed in female controls (17) ($P<0.005$, Table 2, page 16). Analysis of different age groups indicated that PBM-DPD activities in individuals age of 40s and above were slightly higher than that observed with age of 30s (Table 1, page 15; Fig. 2, page 19). However, these differences were not statistically significant. In breast cancer patients, mean PBM-DPD activity was slightly higher in Caucasians compared to African Americans (Fig. 3, page 20). Further examination of affect of race and age on PBM activity by across analysis indicated that these differences were not statistically significant .

Further examination of effect of disease, race, and age on PBM-DPD activity by ANOVA indicated that only the difference of disease (cancer vs. normal subjects) was statistically significant after adjustments for race and age. Mean PBM-DPD activity in breast cancer patients was significantly lower than that observed in patients with colorectal cancer ($P<0.05$, Fig. 4, page 21).

DPD Activities in Uninvolved Liver and Hepatocellular Carcinoma Tissues

DPD activities of 50 paired specimens of uninvolved liver and tumor tissues were quantified in a Chinese patients with hepatocellular carcinoma. The population characteristics of this study are summarized in Table 3 (page 17). The distribution of DPD activities in both uninvolved liver and tumor tissues is shown in Fig. 5, page 22). Statistical analysis by probability testing indicated that DPD activities in both uninvolved human liver and hepatocellular carcinoma tissues follow a normal distribution, with DPD activity in hepatocellular carcinoma being significantly lower than that in uninvolved liver (paired t-test, $P < 0.01$). Of note, a small proportion of uninvolved liver and hepatocellular carcinoma samples had very high DPD activity (Fig. 5, page 22). Further statistical analyses were carried out to compare mean DPD activities between uninvolved liver and

hepatocellular carcinoma among groups classified according to gender and age. In each subgroup, the mean hepatocellular carcinoma DPD activities were consistently significantly lower than that observed in uninvolved liver (P <0.01, Table 3, page 17; Fig. 6, page 23).

The correlation analysis of DPD activity in uninvolved liver and hepatocellular carcinoma is illustrated in Fig. 7 (page 24). No significant linear correlation was observed in the present study (r=0.196, P >0.05).

Pathologic evaluation of each uninvolved liver and hepatocellular carcinoma specimen was performed by microscopic examination in the Department of Pathology at the Sun Yat-sen University of Medical Sciences. Forty-seven of the fifty samples obtained as uninvolved samples were confirmed to be normal liver tissue. Three of the samples showed evidence of hepatic cirrhosis.The DPD activity in these three samples of cirrhotic tissue was not statistically different from that of the samples that appeared normal. All of the tumor specimens were shown to be primary hepatocellular carcinoma of the nodular type, and were classified as grade I to grade III based on WHO standard classification criteria.

DISCUSSION

Task 1. Determine in a prospective study the relationship between DPD activity and 5-FU toxicity

The major purpose of the present project is to characterize the distribution pattern of PBM-DPD activity in breast cancer patients, to establish the relationship between DPD activity and 5-FU-associated toxicity, and to improve 5-FU-based chemotherapy in breast cancer patients by monitoring DPD activity.

Results from the present study demonstrated that PBM-DPD activity in breast cancer patients generally follows a normal distribution as seen in a normal population (17.) However, the major finding of the present study is that mean PBM-DPD activity in breast cancer patients was significantly lower than that observed with the general population. This difference (cancer vs. normal subjects) was statistically significant after adjustments for race and age. In the next year, as described in the Statement of Work of the proposal, we will continue the clinical study examining PBM-DPD activity in breast cancer patients. We will also continue to collect clinical data, e.g., disease status, response, and toxicity. Due to the nature of study design of the project (blinded study), we will not be able to determine the relationship between DPD activity and 5-FU-associated toxicity until the end of clinical study.

In the last two years of the project, we have determined DPD activity of 360 cancer patients, demonstrating that the methods used in monitoring DPD activity is sensitive, accurate, reproducible and can be used in the future large-scale screening in cancer patients. Our study has shown that DPD deficiency is not rare (about 3% in breast cancer patients). Monitoring DPD activity prior to use of 5-FU will have significant impact on reducing 5-FU-associated toxicity and improving therapeutic effects by adjusting the dose to be administered.

A number of drug metabolizing enzymes have genetic polymorphisms (19). To evaluate the distribution pattern of DPD activity and determine if a genetic polymorphism for DPD exists,

several studies have now been undertaken in normal subjects and cancer patient populations (11,12,17,18,23,24). Most of the previous studies utilized a small population without balance in the number of subjects in each subgroup by gender, age, and race. A recent study in our laboratory with 124 subjects (45% males and 55% females) demonstrated a normal distribution of PBM-DPD activity, with an approximate 4-fold difference in enzyme activity (17). No significant differences in the enzyme activity were observed related to gender, age, or race in the general population (17). In a study of cancer patients, Milano *et al.* (18) reported a possible influence of gender on 5-FU clearance and suggested that it may be related to variations in DPD activity. However, more recent reports from the same laboratory showed no significant gender difference in DPD activity (12,25). In the present study, we reported preliminary results of a cohort study of DPD activity in breast cancer patients. PBM-DPD activity was determined in a larger population (360 female breast cancer patients). The distribution pattern of PBM activity was similar to the general population (17). However, the mean enzyme activity was significantly lower than that observed in the general population (17) and lower than that observed in patients with colorectal cancer (Lu and Diasio, unpublished data). Prospective studies of the relationship between DPD activity and 5-fluorouracil-associated toxicity and/or response are continuing.

Task 2 Determine biochemical properties of DPD from peripheral blood mononuclear cells (PBM-DPD) of normal and deficient individuals.

In the initial design of the proposal, we would like to concentrate on the PBM-DPD to elucidate the mechanisms responsible for DPD deficiency. In earlier studies of the project and other projects in this laboratory, we have shown: (1) the correlation between DPD activity and DPD protein in normal human liver; (2) initial evidence for the correlation between DPD activity and DPD protein in peripheral blood mononuclear cells; and (3) initial evidence for the correlation between liver DPD and PBM DPD activity in patients. However, due to the limited amount of PBM-DPD protein available for biochemical and molecular studies, and the importance of liver DPD in 5-FU metabolism, as well as the abundant liver DPD protein available, we decided to use liver sample to carry out most of biochemical studies of DPD.

The population distribution of liver DPD activity has not been known until recently. In a previous study (26), a 288-fold variation in human liver DPD activity was observed, presumably due to variation in the quality of liver tissue preparation. Results from the first year study of the project demonstrated that liver DPD activity generally follows a normal distribution. Slight differences among race, gender, and ages were observed (27). Gender difference in liver DPD activity was shown to be statistically significant (27). Of note, 4 liver samples had very low enzyme activity (<0.05 nmol/min/mg protein) and 3 liver samples had very high enzyme activity (>0.85 nmol/min/mg protein). Although the importance of extremely low DPD activity has been shown in cancer patients with deficiency of this enzyme, the significance of very high enzyme activity has not been clear but may have a role in the poor response to 5-FU treatment due to increased catabolism of the drug.

In the last year, we carried out a study to determine DPD activity in normal and tumor tissues, in collaboration with the Department of Medical Oncology, Cancer Hospital, Sun Yat-sen University of Medical Sciences in Guangzhou, China. One of the advantages of the study is that we could determine the normal and tumor tissue simultaneously to establish the relationship between normal and tumor tissues. Fifty cancer patients were enrolled in the present study. All patients were diagnosed with primary hepatocellular carcinoma that was relatively small and surgically removable. Each sample was divided into two parts, one being used for pathologic evaluation and the other for DPD analysis. Statistical analysis by probability testing indicated that DPD activities in

both uninvolved human liver and carcinoma tissues follow a normal distribution, with DPD activity in tumor being significantly lower than that in uninvolved liver (paired t-test, $P < 0.01$). Further statistical analyses showed that the mean DPD activities in uninvolved liver and hepatocellular carcinoma among groups classified according to gender and age were not significantly different. However, in each subgroup, the mean tumor DPD activities were consistently significantly lower than that of the mean uninvolved liver DPD activities. Of note, mean liver DPD activity (0.45 ± 0.02) was higher thanin normal population (0.37 ± 0.02). The mechanism for the difference is not clear.

In a continuing effort to study DPD in this laboratory, we have generated a specific polyclonal antibody against human DPD. Using this antibody, both decreased liver DPD activity and decreased protein corresponding to this enzyme were observed in cancer patients identified to be deficient of this enzyme (17). Studies have now shown the usefulness of the polyclonal antibody in quantitating DPD activity in various tissues including liver (27), peripheral blood mononuclear cells (28), and fibroblasts (29). Using a larger sample size in the present study, we further established the relationship between DPD activity and the amount of DPD protein, providing the insight of DPD deficiency and the basis for the future clinical use of DPD antibody to quantify DPD activity in cancer patients.

CONCLUSIONS

Thus far, studies in the present project have demonstrated that: 1) Dihydropyrimidine dehydrogenase activity in peripheral blood mononuclear cells in the breast cancer population generally follows a normal distribution with slight differences in age and race Significantly decreased DPD activity was observed in breast cancer patients compared to normal population; and 2) Liver dihydropyrimidine dehydrogenase activity in the general population and the cancer population generally follows a normal distribution with slight differences in gender, age and race. Significantly decreased DPD activity was associated with decreased enzyme protein. DPD activity in tumor tissue is significantly lower than normal liver tissues.

Further studies are needed to determine the frequency of DPD deficiency in the cancer patient population, prospectively determine the relationship between DPD activity and 5-FU effectiveness and/or toxicity, the relationship between DPD activities in peripheral blood mononuclear cells and the liver, and the molecular basis for DPD deficiency.

ACKNOWLEDGEMENTS

I sincerely thank Dr. Robert B. Diasio for his encouragement, advise, and discussion. This study was supported by US Army grant DAMD17-94-J-4115 (to Dr. Zhihong Lu) and USPHS/NIH grant CA-64214 (to Dr. Robert B. Diasio).

I thank Dr. Ruiwen Zhang for helpful discussion in study design and data analysis, Dr. Wenqi Jiang, Dr. Jieming Yan, Ms. Hongling Xiao, Ms. Demona Fletcher, Mr. Ted H. Krayer, and Ms. Hongyong Cai for their excellent technical assistance, Dr. Tiepu Liu for assistance in statistical analysis, and the following medical oncologists for their interest and collaboration in the studies: Dr. J. Carpenter, Dr. S. Ferguson, Dr. A.F. Lobuglio, Dr. R. Wheeler, and Dr. Youjian He.

REFERENCES

1. Diasio, R.B. and Harris, B.E. Clinical pharmacology of 5-fluorouracil. Clin. Pharmacokinetics 16:215-237, 1989
2. Daher, G.C., Harris, B.E., and Diasio, R.B. Metabolism of pyrimidine analogues and their nucleosides. Pharmacol. and Therapy. 48:189-222, 1990
3. Scrip's Cancer Chemotherapy Report, Scrip World Pharmaceutical News, PJB Publications Ltd, London, 1992
4. Chabner, B.A. and Myers, C.E. Clinical pharmacology of cancer chemotherapy: In Cancer - Principles and Practice of Oncology (3rd Ed), pp. 349 -395, DeVita, V.T., Hellman, S., and Rosenberg, S.A. (eds), Lippincott, Philadelphia, 1989
5. Schilsky, R. L. Antimetabolites. in The Chemotherapy Source Book, pp 306-308, Perry, M.C., Williams and Wilkins, Baltimore, 1992
6. Shiotani, T. and Weber, G. Purification and properties of dihydrothymine dehydrogenase from rat liver. J. Biol. Chem. 256:219-224, 1981
7. Au, J.L., Rustum, Y.M., Ledesma, E.J., Mittleman, A., and Creaven, P.J. Clinical pharmacological studies of concurrent infusion of 5-Fluorouracil and thymidine in treatment of colorectal carcinomas. Cancer Res. 42:2930-2937,1982
8. Woodcock, T.M., Martin, D.S., Damin, A.E.M., Kemeny, N.E., and Young, C.W. Combination clinical trials with thymidine and fluorouracil: a phase I and clinical pharmacologic evaluation. Cancer 45:1135-1143, 1980
9. Lu, Z., Zhang, R., and Diasio, R.B. Purification and characterization of dihydropyrimidine dehydrogenase from human liver. J. Biol. Chem. 267:17102-17109, 1992
10. Petit, E., Milano, G., Levi, F., Thyss, A., Bailleul, F., and Schneider, M. Circadian rhythm-varying plasma concentration of 5-fluorouracil during a five day continuous venous infusion at a constant rate in cancer patients. Cancer Res. 48:1676-1679, 1988
11. Harris, B.E., Song, R., Soong, S.J. and Diasio, R.B. Relationship of dihydropyrimidine dehydrogenase activity and plasma 5-fluorouracil levels: evidence for circadian variation of 5-fluorouracil levels in cancer patients receiving protracted continuous infusion. Cancer Res. 50:197-201, 1990
12. Fleming, R.A., Milano, G., Thyss, A., Etienne, M-C.,Renee, N., Schneider, M., and Demard, F. Correlation between dihydropyrimidine dehydrogenase activity in peripheral mononuclear cells and systemic clearance of fluorouracil in cancer patients. Cancer Res. 52:2899-2902, 1992
13. Tuchman, M., Stoeckeler, J.S. Kiang, D.T., O'Dea, R.F., Rammaraine, M.L. and Mirkin, B.L. Familial pyrimidinemia and pyrimidinuria associated with severe fluorouracil toxicity. New Engl. J. Med. 313:245-249, 1985
14. Diasio, R.B., Beavers, T.L., and Carpenter, J.T. Familial deficiency of dihydropyrimidine dehydrogenase. J. Clin. Invest. 81:47-51, 1988
15. Harris, B.E., Carpenter, J.T., and Diasio, R.B. Severe 5-fluorouracil toxicity secondary to dihydropyrimidine dehydrogenase deficiency: a potentially more common pharmacogenetic syndrome. Cancer 68:499-501, 1991
16. Lilenbaum, R.C., Harris B.E., Diasio R.B., Naes, J. and Lyss, A.P. Heterozygosity for dihydropyrimidine dehydrogenase (DPD) deficiency may result in life threatening (Gr4) toxicity from fluorouracil (FUra). Proc. Amer. Soc. Clin. Oncol. 10:120, 1991

17. Lu, Z.H., Zhang, R., and Diasio, R.B. Dihydropyrimidine dehydrogenase activity in human peripheral blood mononuclear cells and liver: population characteristics, newly identified deficient patients, and clinical implication in 5-fluorouracil chemotherapy. *Cancer Res.* 53: 5433-5438, 1993
18. Milano, G., Etienne, M.C., Cassuto-Viguier, E., Thyss, A., Saantini, J., Frenay, M., Renee, N., Schneider, M., and Demard, F. Influence of sex and age on fluorouracil clearance. J. Clin. Oncol. 10: 1171-1175, 1992
19. Meyer U.A., Zanger, U.M., Skoda, R.C., Grant, D. and Blum, M. Genetic polymorphisms of drug metabolism. Progress in Liver Diseases 9:307-323, 1990
20. Sommadossi, J.P., Gewirtz, D.A., Diasio, R.B., Aubert, C., Cano, J.P. and Goldman, I.D. Rapid catabolism of 5- fluorouracil in freshly isolated rat hepatocytes as analyzed by high performance liquid chromatography. J. Biol. Chem. 257:8171-8176, 1982
21. Bradford, M. A Rapid sensitive method for the quantitation of microgram qualities of protein utilizing the principle of protein-dye binding. Anal. Biochem. 72:258-254, 1976
22. Towbin, H., Staehelin, T., and Gorden, J. Electrophoretic of proteins from polyacrylamide gels to nitrocellulose sheets: procedure and some applications. Proc. Natl. Acad. Sci U.S.A. 76: 4350-4354,1979
23. Heggie, G.D., Sommadossi, J.P., Cross, W.J., Huster W.J. and Diasio R.B. Clinical pharmacokinetics of 5-fluorouracil and its metabolites in plasma, urine, and bile. Cancer Res. 47:2203-2206, 1987
24. Etienne, M.C., Lagrange, J.L., Dassonville, O., Fleming, R., Thyss, A., Renee, N., Schneider, M., Demard, F., and Milano, G. A population study of dihydropyrimidine dehydrogenase in cancer patients. J. Clin. Oncol. 12: 2248-2253, 1994
25. Fleming, R.A., Milano, G.A., Gaspard, M.H., Bargnoux, P.J., Thyss, A., Plagne, R., Renee, N., Schneider, M., and Demard, F. Dihydropyrimidine dehydrogenase activity in cancer patients. Eur. J. Cancer 29A:740-744, 1993
26. Ho, D.H., Townsend, L., Luma, M.A., and Bodely, G.P. Distribution and inhibition of dihydrouracil dehydrogenase activities in human tissues using 5-fluorouracil as a substrate. Anticancer Res. 6: 781-784, 1986
27. Lu, Z., Zhang, R., Diasio, R.B. Population characteristics of hepatic dihydropyrimidine dehydrogenase activity, A key metabolic enzyme in 5-fluorouracil chemotherapy. Clin. Pharmacol. Ther. 58: 512-522,1995.
28. Takimoto, C., Lu, Z., Zhang, R., Liang, M., Larson, L., Grem, J.L., Allegra, C.L., Diasio, R.B., Chu, E. Severe Neurotoxicity following 5-fluorouracil-based chemotherapy in a patient with dihydropyrimidine dehydrogenase deficiency. Clin Cancer Res. 1996; 2:477-481.
29. Diasio, R.B., Van Kuilenburg, A.B.P., Lu, Z., Zhang, R., Van Lenthe, H., Bakker, H.D., Van Gennip, A.H. Determination of dihydropyrimidine dehydrogenase (DPD) in fibroblasts of a DPD deficient pediatric patient and family members using a polyclonal antibody to human DPD. In: Purine and Pyrimidine Metabolism in Man VIII, Edited by Sahota, S., and Taylor, M., Plenum Press, New York, pp. 7-10, 1995

Table 1. Dihydropyrimidine Dehydrogenase Activity in Peripheral Blood Mononuclear Cells (PBM-DPD) in Breast Cancer Patients

Group	n	DPD Activity (nmol/min/mg protein) Mean ± S.E.	Highest	Lowest
Total	360	0.265 ± 0.006	0.571	0.013
African American	48	0.243 ± 0.014		
Caucasian	312	0.270 ± 0.006		
Age (yr)				
30-	35	0.230 ± 0.015		
40-	108	0.265 ± 0.010		
50-	113	0.274 ± 0.009		
60-	61	0.282 ± 0.014		
70-	43	0.265 ± 0.019		

Table 2. Comparison of PBM-DPD Activity between Breast Cancer Patients and Health Volunteers

Group		DPD Activity (nmol/min/mg protein, Mean ± S.E.)	
		Breast Cancer	Health Volunteers
Women		0.265 ± 0.006	0.443 ± 0.016
African American		0.243 ± 0.014	0.460 ± 0.026
Caucasian		0.270 ± 0.006	0.431 ± 0.020
Age (yr)	20-		0.413 ± 0.014
	30-	0.230 ± 0.015	0.456 ± 0.021
	40-	0.265 ± 0.010	0.431 ± 0.030
	50-	0.274 ± 0.009	0.373 ± 0.031
	60-	0.282 ± 0.014	
	70-	0.265 ± 0.019	

Table 3. Dihydropyrimidine Dehydrogenase Activity in Hepatoma and Uninvolved Liver in Cancer Patients

Group		n	DPD Activity (nmol/min/mg Protein)					
			Uninvolved Liver			Hepatocellular Carcinoma Tissue		
			Mean ± S.E.	Highest	Lowest	Mean ± S.E.	Highest	Lowest
Total		50	0.45 ± 0.02	0.85	0.19	0.34 ± 0.03	1.45	0.02
Men		43	0.45 ± 0.02	0.85	0.19	0.35 ± 0.03	1.45	0.07
Women		7	0.38 ± 0.02	0.45	0.28	0.31 ± 0.08	0.70	0.02
Age (yr)	30-	8	0.47 ± 0.06	0.73	0.32	0.22 ± 0.03	0.34	0.11
	40-	24	0.44 ± 0.03	0.78	0.19	0.38 ± 0.06	1.45	0.02
	50-	9	0.43 ± 0.06	0.85	0.19	0.34 ± 0.05	0.61	0.15
	60-	9	0.44 ± 0.06	0.80	0.22	0.36 ± 0.06	0.63	0.06

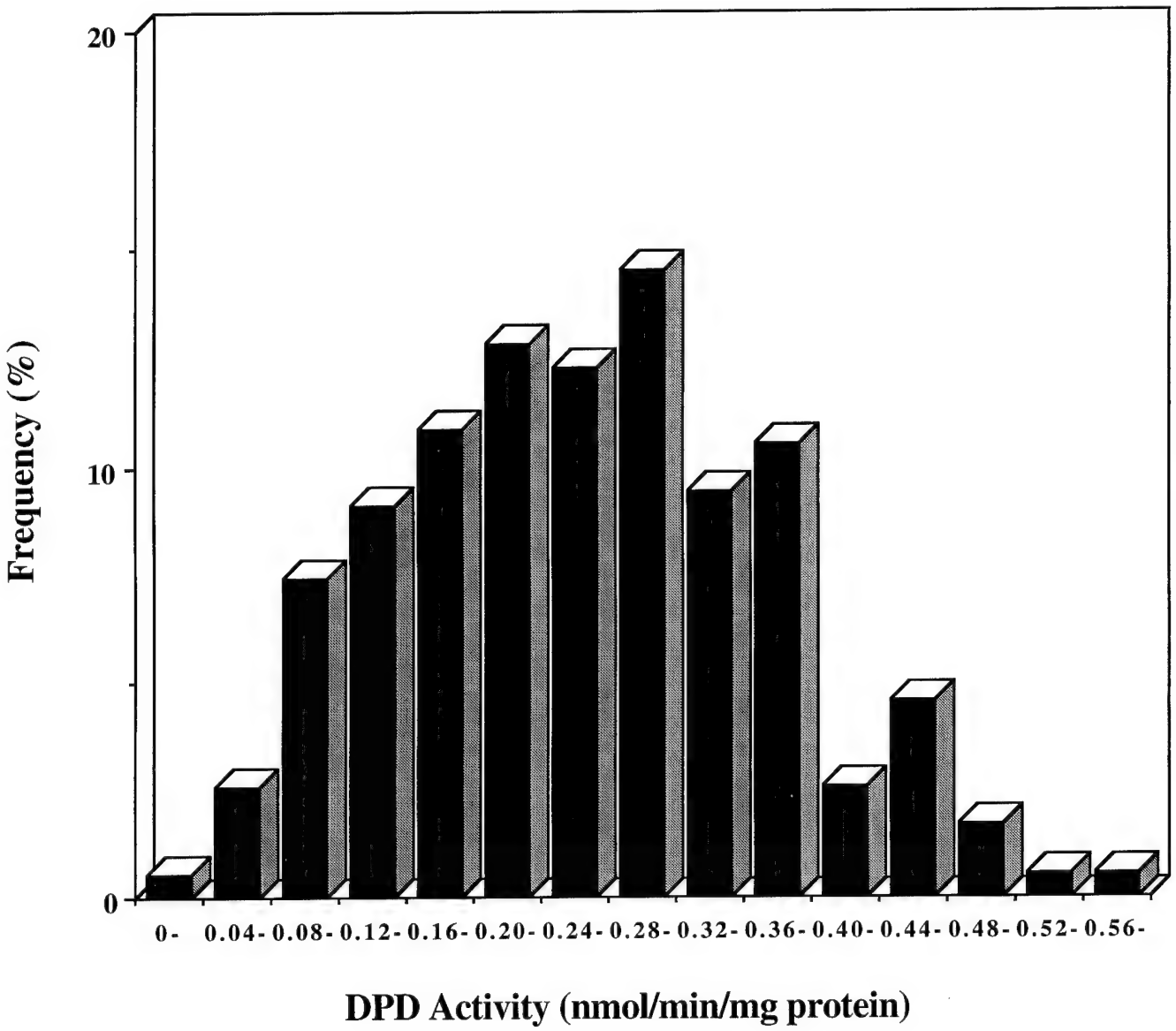

Fig.1 Population Distribution of PBM-DPD Activity in Breast Cancer Patients. Statistical analysis demonstrated that PBM DPD activity follows a normal distribution (Guassian distribution).

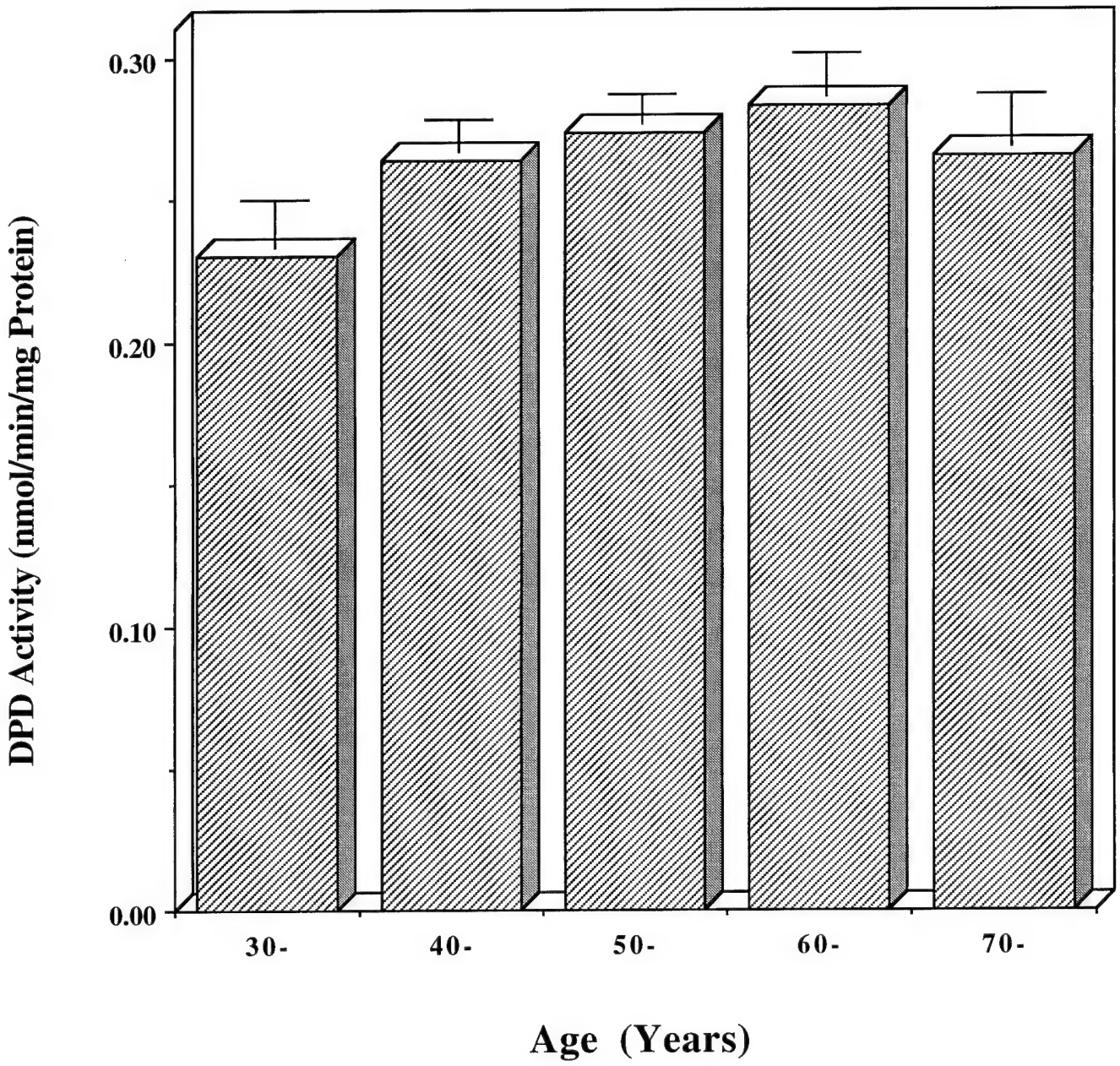

Fig.2 Population Distribution of PBM-DPD Activity in Breast Cancer Patients by Age.

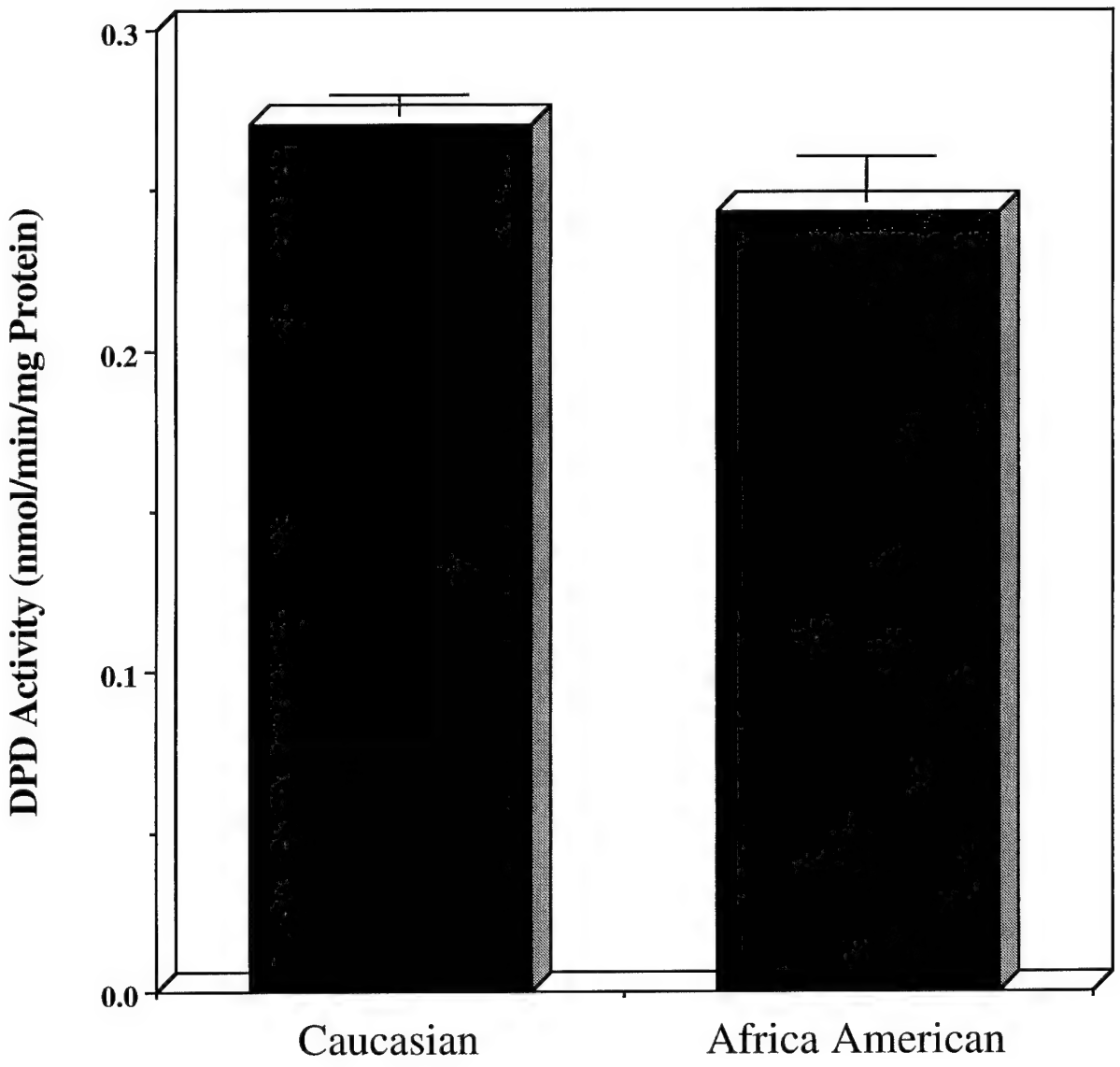

Fig. 3 Population Distribution of PBM-DPD Activity in Breast Cancer Patients. This figure illustrates the comparison of mean (± S.E.) DPD activities between african americans and caucasians.

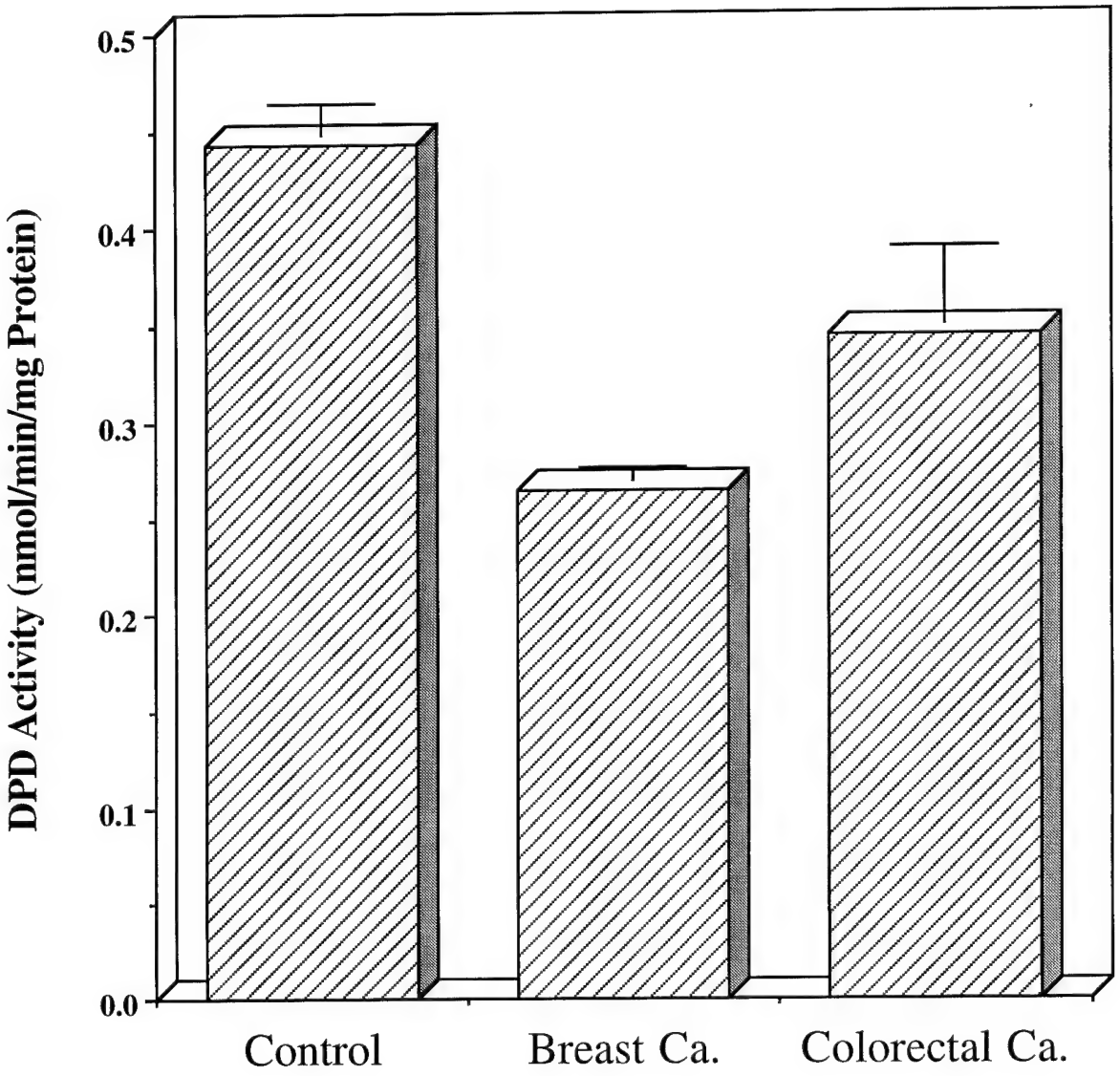

Fig. 4 Comparison of Mean PBM-DPD Activity in Different Population
This figure illustrates the comparison of mean (± S.E.) DPD activities between breast cancer patients and normal controls and colorectal cancer patients. Data of the normal controls are from our previous studies (ref. 17). Data of the colorectal cancer patients are from an on-going study in our laboratory (Lu and Diasio, unpublished data).

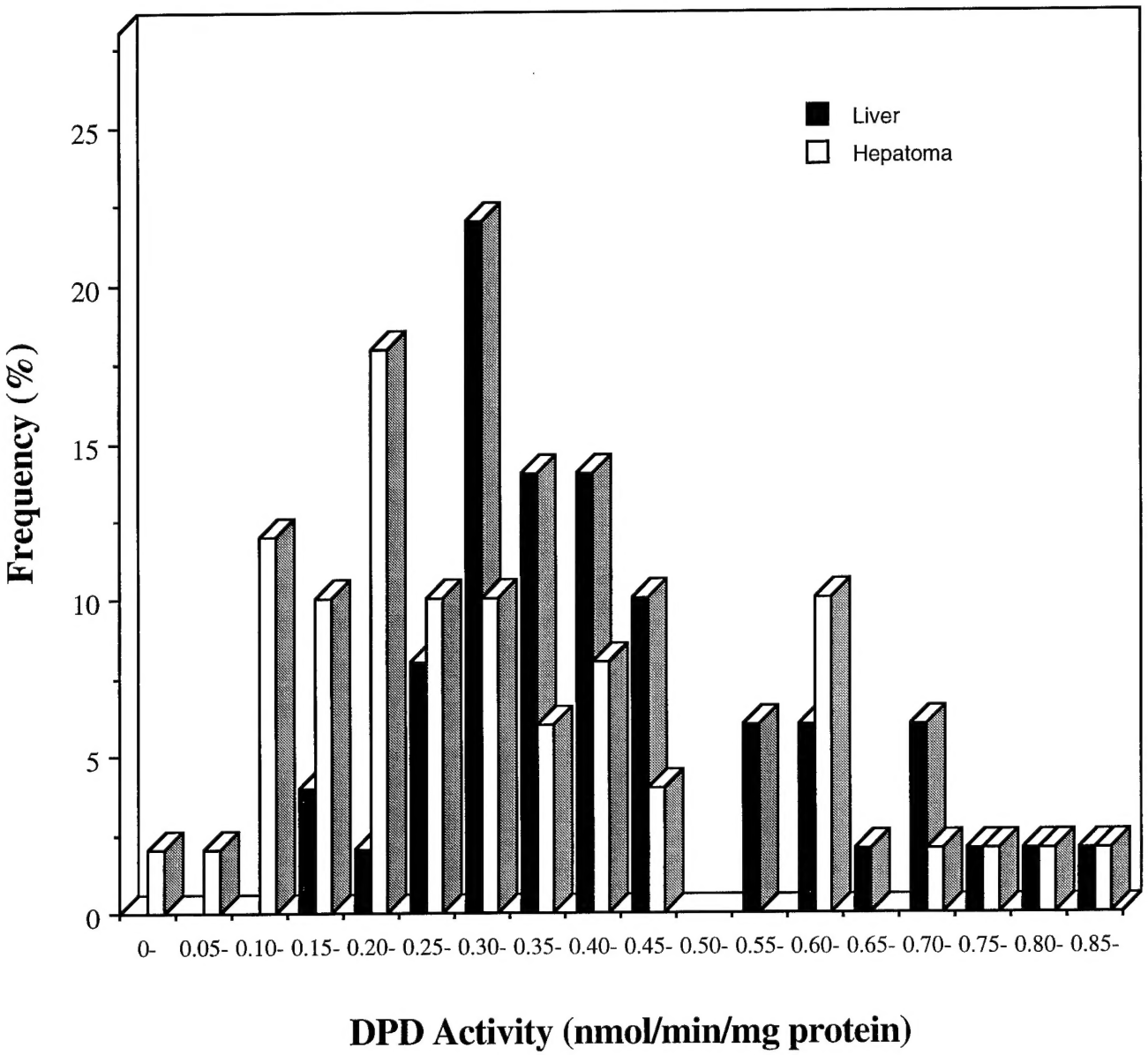

Fig. 5 Population Distribution of DPD Activity in Uninvolved Liver and Hepatocellular Carcinoma

Statistical analysis demonstrated that DPD activity follows a normal distribution (Guassian distribution) in both uninvolved liver and hepatocellular carcinoma.

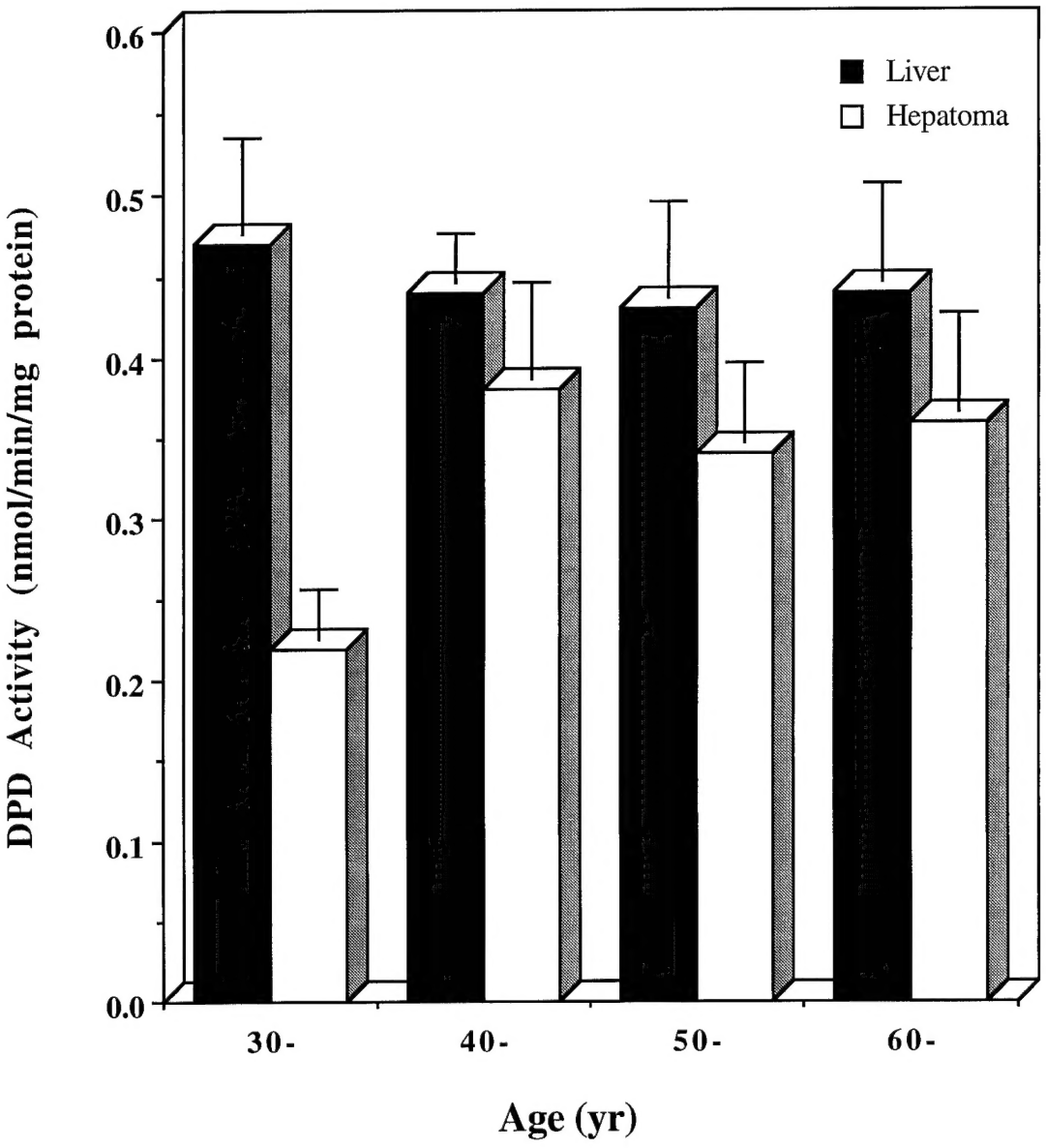

Fig. 6 Comparison of Population Distribution of DPD Activity in Uninvolved Liver and Hepatocellular Carcinoma by Age
Statistical analysis demonstrated that DPD activity in uninvolved liver is significantly higher than that in hepatocellular carcinoma in each age group.

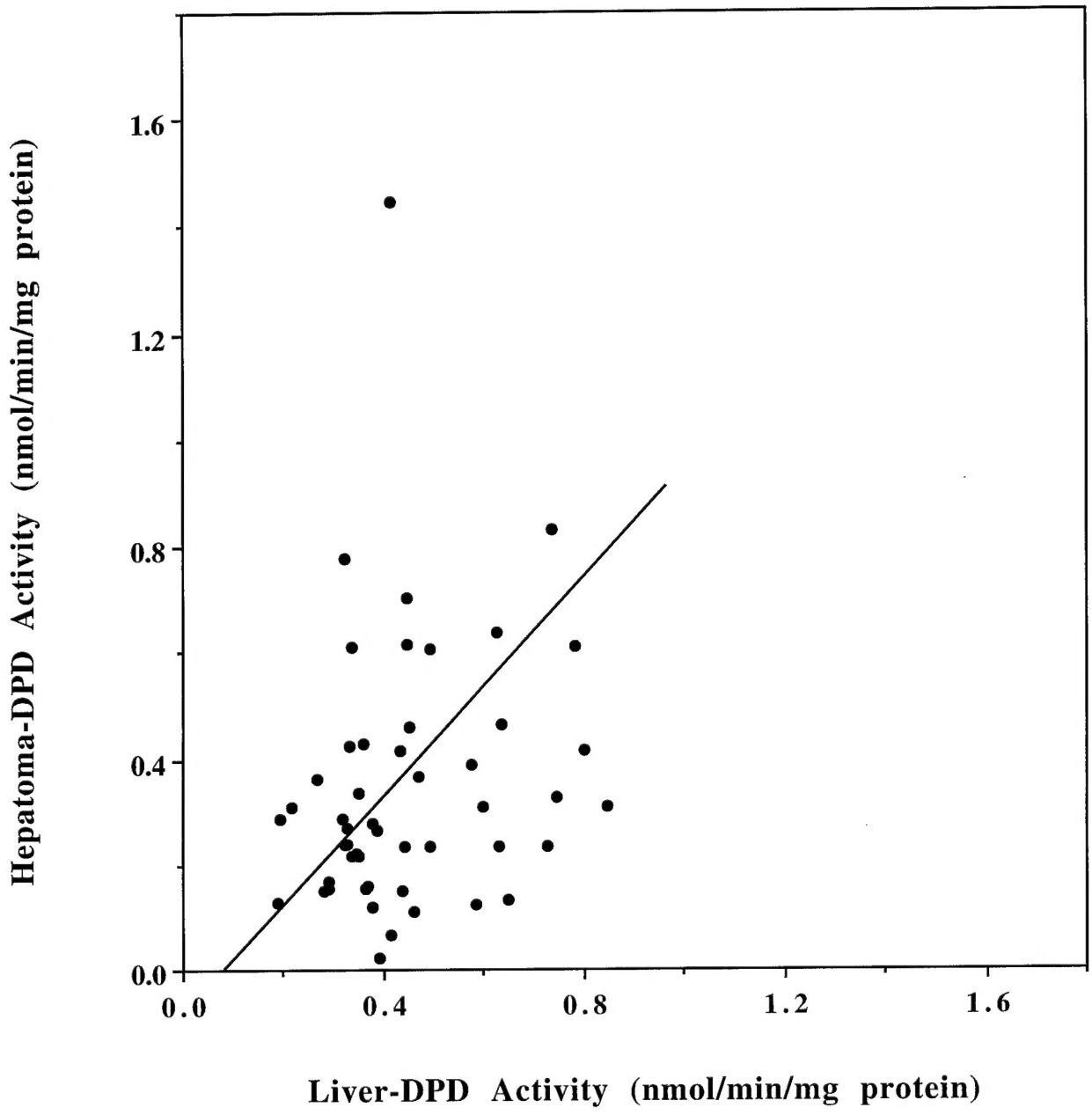

Fig. 7 Correlation Analysis of DPD Activity between Uninvolved Liver and Hepatocellular Carcinoma
No linear correlation is indicated the uninvolved liver DPD activity and DPD activity in hepatocellular carcinoma ($r = 0.196$, $p>0.05$).

APPENDIX

UPDATED LIST OF PUBLICATIONS AND PRESENTATIONS RELATED TO THIS GRANT

Original Papers

1. **Lu, Z.**, Zhang, R., Diasio, R.B. Population characteristics of hepatic dihydropyrimidine dehydrogenase activity, A key metabolic enzyme in 5-fluorouracil chemotherapy. Clin. Pharmacol. Ther. 58: 512-522,1995.

2. Diasio, R.B., Van Kuilenburg, A.B.P., **Lu, Z.**, Zhang, R., Van Lenthe, H., Bakker, H.D., Van Gennip, A.H. Determination of dihydropyrimidine dehydrogenase (DPD) in fibroblasts of a DPD deficient pediatric patient and family members using a polyclonal antibody to human DPD. In: Purine and Pyrimidine Metabolism in Man VIII, Edited by Sahota, S., and Taylor, M., Plenum Press, New York, pp. 7-10, 1995

3. Takimoto, C., **Lu, Z.**, Zhang, R., Liang, M., Larson, L., Grem, J.L., Allegra, C.L., Diasio, R.B., Chu, E. Severe Neurotoxicity following 5-fluorouracil-based chemotherapy in a patient with dihydropyrimidine dehydrogenase deficiency. Clin Cancer Res. 1996; 2:477-481.

4. Jiang, W., **Lu, Z.**, He, Y., Diasio, R.B. Dihydropyrimidine dehydrogenase activity in hepatocellular carcinoma; implication for 5-fluorouracil-based chemotherapy. Clin.Cancer Res. Submitted.

Book Chapters

1. Diasio, R.B., **Lu, Z.**, Zhang, R,, Shihanian, H. Fluoropyrimidine Catabolism. In: Concepts, Mechanisms, and New Targets for Chemotherapy (Muggia F, ed.), Kluwer Academic Publishers, Boston, MA, 1995, pp. 71-93.

2. **Lu, Z.**, Diasio RB. Polymorphic Drug-Metabolizing Enzymes. In: Principles of Antineoplastic Drug Development and Pharmacology (Schilsky, R. L., Milano, G. A., and Ratain, M. J., eds.), Marcel Dekker, New York, NY, 1996, pp. 281-305.

Abstracts/Presentations

1. Amin, G., Shahinian, H., Miller, D., Vukelj, S., Zhang, R., **Lu, Z.**, Diasio, R.B. Severe neurotoxicity following 5-fluorouracil (FUra) chemotherapy in patients with dihydropyrimidine dehydrogenase (DPD) deficiency. Pro. Am. Soc. Clin. Oncol. 1995; 14: 169 (Abstract # 361).

2. Takimoto, C., **Lu, Z.**, Zhang, R., Liang, M., Larson, L., Grem, J.L., Allegra, C.L., Chu, E. Severe neurotoxicity following 5-fluorouracil-based chemotherapy in a patient with dihydropyrimidine dehydrogenase deficiency.Clin. Pharm. Ther. 1996; 59: 161.

3. **Lu, Z.**, Zhang, R., Carpenter, J., Yan, J., Diasio, R.B. Decreased dihydropyrimidine dehydrogenase (DPD) activity in breast cancer patients; Potential increased risk for 5-fluorouracil toxicity. Proc. Am. Assoc. Cancer Res. 1996; 37: 184. (1996 Glaxo Wellcome Oncology Clinical Research Scholar Award- American Association For Cancer Research).